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THE NATICK LANDFORM CLASSIFICATION SYSTEM

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This report provides a description of the landform classification system developed by the US Army Natick Laboratories for AMSAA environmental evaluations, employing maximum hill height, modal hill height, and number of positive features per mile as criteria, together with the development rationale and limitations. Instructions for using the code to classify other areas and suggestions for expansion of the system are given.

FOREWORD

The Earth Sciences Laboratory of the US Army Natick Laboratories was requested by USAMSAA (US Army Materiel Systems Analysis Activity) under PRON No. A1-0-90060-01-AJ-BG to develop a technique to classify landform regions according to differences in line-of-sight characteristics. A code was developed and employed in constructing maps of a number of landform regions in the Federal Republic of Germany, South Vietnam, Western Thailand, and Northeastern United States with particular application to intervisibility evaluation. It was found that terrain data classified under this scheme could be related quantitatively to specific features in other areas around the world using source material available in this country.

A number of sample landform areas have been digitized (x,y,z coordinates at regular intervals), both from topographic maps developed by Natick Laboratories and from US Defense Mapping Agency and foreign sources. The Natick Laboratories developed maps having one-meter contour intervals, to enable us to study the partial masking effects of terrain irregularities not illustrated on the typical "Standard A" military map (a tank company can be hidden in a 20-meter contour interval).

Several models, developed by Mr. Warren K. Olson of AMSAA, are used to examine line-of-sight existence, area masking, and terrain shape from any vantage point. The models, together with the landform classification system and digitized sample regions, are useful for studies of sensor observation capabilities, direct-fire weapons, laser designators, flare illumination, target availability time, and as input to war games.

The landform classification system developed by Natick Laboratories provides a quantitative measure of the general applicability of the results of field experiments and studies that are based on only one or two terrain regions. It has been applied by AMSAA in comparison of terrain at one US test site (Hunter Liggett Military Reservation, US Army Combat Development Experimentation Command), a region near Aberdeen Proving Ground, and selected areas in Germany. It was used by Natick Laboratories to show terrain analogs between Germany and the United States, and between Vietnam and Thailand. Additional comparisons are under study.

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1. INTRODUCTION

1.1. Objective.

The AMSAA objectives in the evaluation of the masking effect of landforms included the need for a system to describe differences in intervisibility in various regions world-wide and the estimation of line-of-sight probability as a function of range and terrain roughness that could be utilized in personnel exposure problems and studies of materiel systems effectiveness.

The purpose of this report is to describe the rationale for, and development of, the US Army Natick Laboratories landform classification system, and the recommended procedure for using this system.

1.2 Background.

The present investigation borrowed from pioneer work in landform classification conducted at Natick Laboratories by Wood and Snell (1957, 1958, 1959, 1960) Anstey (1963, 1964, 1965, 1966) and by Hammond at the University of Wisconsin (1954). These studies were aimed primarily toward the systematization and logical interpretation of terrain data to assist in the determination of design criteria for materiel, and secondarily toward the development of a universal system for the quantification of landform data. While not specifically oriented toward intervisibility, the analysis of line-of-sight profiles was an integral element in these investigations, and an evaluation of descriptors of landform physiognomy was conducted.

Limitations in time and funding restricted the present study to secondary data sources (tactical scale maps and aerial photographs) and to the use of a sampling technique (profiling) to obtain pertinent descriptors. A part of the initial instructions placed the emphasis of the investigation on the terrain of the Federal Republic of Germany together with its analogous regions in the glaciated area of Northeastern United States. The evolved classification system may be expected to provide a point of departure for a series of investigations on further quantification of landform physiognomy.

2. DEVELOPMENT OF THE CLASSIFICATION SYSTEM

2.1 Criteria for Intervisibility.

One of the specific relationships of line-of-sight probability studies and the terrain in which it is conducted is obscuration or the screening effect caused by the interference of higher elevations between the elevation of the observer and that of the observed. Therefore,

the major topographic considerations for study in any line-of-sight problem are the height and number of hills that would interfere with intervisibility. It is recognized that size and shape of vegetation and buildings as well as atmospheric effects are also limiting conditions for visibility distance, but they are not a part of the present study.

2.1.1 Maximum Hill Height (local relief). In the present study the first parameter to be determined was maximum hill height (see Table 1). It is defined as the difference in elevation of the highest and lowest points on a map. These points were connected by a line-of-sight profile (see Figure 1) which resulted in a continuous but irregular "slope" between the two points. It is recognized that normally there will be numerous irregularities or "peaks" along the profile which must be considered because of their masking effect on intervisibility. Due to the necessity of differentiating the maximum hill height from all of the other "peaks" or hills shown on the profile, each with its own upslope and downslope relief, it was decided to refer to this first digit in the code as maximum hill height (local relief). In other words, it is local relief of the map area. Maximum hill height is not the relief to an adjacent valley if there is a lower valley on the same map sheet, and it is not the elevation above sea level of the highest point on the map.

This digit initially classifies the entire large-scale map on which it is located, unless the locations of nickpoints along the profile show that most of the map is of a different relief classification (i.e., belonging to a higher or lower elevation area shown on an adjacent map). In the original planning the first digit of the classification system was the sole regional index and would have been labeled as the actual range of relief found in the region. This plan was satisfactory in the lowlands but could not be used in mountains because of the several modifiers required to adequately describe each of a large number of diverse small areas which occur there. For this reason, the first digit (numeric) refers to the ranges of relief in the classification (see Figure 2).

Frequency diagrams were compiled to show the range of variation in descriptor characteristics that could be found within a region, as well as the number of times the values occur. The central tendency of the data in Figures 3.a - 3.f shows the nature of regional adherence to the classification scheme. In some instances these figures show that values were included which exceed the range of the original classification. This was the result of combining tiny regions, that would be difficult to show on a map of small scale within a larger region. On a large scale map, these tiny areas would be indicated as separate regions. The incidence of values found in a region beyond the range of the original classification shows a need for redesignation of the regional descriptor. The small sample size shown for Region 6 results in a double maximum, but this probably would disappear with an increase in the sample size. Another problem is illustrated for Region 5, where a number of occurrences in the

range 451 to 475 indicates that these slopes probably should have been in Region 6, but because of their small areal extent they were included within Region 5.

A large incidence of values (peak) for one descriptor at either end of the histogram, or a double maximum within the histogram usually indicates that the region is not homogeneous in terms of the selected criteria or class interval. If the peaks are closely spaced, the plot may indicate that the arbitrary division between classes is actually dividing a natural region, and the interval should be changed in a future reclassification scheme or a modification of the present scheme. The outer limits shown in Figures 3a thru 3f thus become the actual descriptors of the region regardless of the central tendency of the data.

The map grid derived from plotting the borders of the 1:50,000 scale sheets on a national or continental map gives a convenient means for arbitrary compartmentalization within the broad natural compartments. The maximum hill height on each of these map sheets is an essential feature of the classification scheme. This arbitrary compartmentalization reserves the local relief data for various possible sub-region uses. There is no intention of combining all upland area and classifying it according to the highest elevation found in the whole area. Rather, the objective is to sort out those portions of the uplands and lowlands which have common characteristics, even though these may be very small regions or subregions, and may require some subsequent regrouping for mapping purposes (see Figure 4).

The scale at which the classification is to be plotted determines the amount of area included in each class. Obviously, narrow, flat bottomed valleys in mountainous regions, while clearly delimited on large scale maps, cannot be accurately depicted as separate regions on small scale maps, and would be shown as an integral part of a large mountainous region. Also, a small isolated peak standing above its neighbors cannot be accurately delimited and labeled except on a very large scale map. If all landscape features are plotted on very large scale maps, the individual differences between landforms are clearly seen, and using the present classification system, each slope can be identified and described quantitatively. For example, at a scale of 1:5,000, areas as small as 10 meters square can be delimited and classified. When considering an area as large as the Federal Republic of Germany or Northeastern United States, it is necessary to group individual small landscape features into traditional large landform units (plains, mountains, hills etc.) which can be differentiated quantitatively.

Figure 2 shows the landforms in the Fritzlar district of Germany, an area of approximately 21 X 22 km, which permits detailed demarcation of landform regions. Note, however, that on the map of the Federal Republic of Germany (Figure 5) it is impossible to show the lowland detail, and consequently, the entire region is given the classification of the highlands. In general, transfer and conversion

of regional information between maps of different scales causes loss of detail going to smaller map scales or over-generalization when going to larger map scales.

Each of the 100 meter grid areas on the Fritzlar diagram has a specific highest elevation, but this mass of data has no meaning for the district as a whole without a means of compartmentalizing it. Data to be used in studies of comparability must all be obtained from the same sized area and from materials of the same scale and contour interval.

2.1.2 Modal Hill Height (modal local relief). The modal hill height (modal local relief) was determined by assigning an alphabetic code (see Table 1) to each slope in each profile, and finding the frequency of occurrence of each relief category for all of the profiles drawn for each map sheet. These were later combined for all portions of continuous map sheets falling within the same maximum hill height category. The letter code, representing the most frequently occurring category, was used as the first modifier of the landform region designator, (maximum hill height) and as an indicator of a sub-region.

Some rare bi-modal slope conditions were found within a single region. Normally, the most frequent incidence is shown immediately after the maximum hill height indicator, and, if significant, the second most frequent incidence is shown. In most instances there is only one mode, but if a second sample size is nearly as large it should be recognized in the region code as a second modifier.

Isolated hill masses (inselbergs) in a lower hilly area, or a series of lower valleys in a relatively higher hilly area, normally result in different local relief sample sizes in the slope frequency study. Although these conditions indicate a need for further division of subregions, there was not time in the present study to construct the large number of profiles that would have been required to determine additional subregions with two modal hill height designators (see Figure 6).

Additional slope samples usually removed the bi-modal problem, but it usually did not change the regional boundary or the high incidence of slopes in a different classification category. A change in class intervals also failed to remove the duality, inasmuch as these occurred in categories A thru K, the entire range.

2.1.3 Positive Features Per Mile. The number of positive features per mile is the usual second modifier in the classification code (see Table 1). This number is the average frequency of all "peaks" on all of the profile segments which fall within a given maximum hill height category. In this classification system a positive feature must have more than 10 feet (3 meters) of relief on both its upslop and downslope sides. This average is an index of terrain roughness in the region.

The final classification of each of the subregions resulted from the application of the above three parameters. For example, if an area has a maximum local relief of 20 meters it is classified as Region 2, if all of the hills within this region are less than 33 feet high it is further designated as 2A; if one part of this region has an average of one hill per mile of traverse it is classified as 2Ab; another part with less than 0.5 hills per mile is 2Aa.

Insofar as bare terrain is a concern, the greatest intervisibility would be found in regions classified as 1Aa. The amount of intervisibility decreases as one enters regions with higher numbers, except that isolated mountain summits may have extremely good intervisibility while masking visibility from lowland positions. As the number of positive features per mile increases the resultant visibility masking increases. A combination of high elevations and large numbers of positive features usually indicates poor intervisibility.

Originally, it had been planned to show all of the modifying numbers in each of the subregions, but this plan was abondoned because of spatial restrictions as well as the difficulty of interpreting the mass of numbers presented. The addition of another descriptive parameter would further add to the number of digits to be shown, and would decrease the size of present subregions.

The identification of specific landform types, such as kames or barchans, can seldom be made from tactical scale maps. These features must be identified in the field or from low-level aerial photographs.

2.2 Profile Selection.

Evaluations of the shapes of landforms (i.e., flatness, linearity, massiveness, serrativity, etc.) were not included in the study because of the profiling technique employed for obtaining physiognomic data. The profile is a standard line-of-sight technique, and, in addition, provides a valuable means for sampling landforms from secondary sources. The time and effort involved in measuring every slope in a study area would be not only prohibitive, but would yield so much information that any comprehendible evaluation would require a summary and categorization such as that provided by selected profiles.

Closely spaced profiles, however show the effect of landform shape in intervisibility studies. The number of profiles required in any area, or grid, depends on the intended use of the data. For example, trafficability research requires a finer grid than that normally used in design criteria determinations. In order to develop a means of classifying large areas with the minimum number of homogeneous characteristics, it was not possible to evaluate all of the profiles that would appear in a fine grid. In the initial research a 500-meter parallel spacing was used, but this gave only a small amount of regional information that

could not be obtained from a one-kilometer spacing requiring half the time. The time involved in adequately analyzing the large number of profiles generated with this latter spacing was considered to be too costly to meet the needs of AMSAA. Also, the results were not significantly better than those obtained from 3 or 4 profiles taken from a topographic map at the scale of 1:50,000.

It was found that local repetition of profile data required for the development of a classification system (i.e., number and height of "peaks" along a profile) was not productive. An expensive employment of this type of effort did not further either the accuracy or the comprehensiveness of the system. In like manner, it was found that random sampling by means of one or two profiles across a 1:50,000 scale map often missed the essential characteristics of intervisibility determination.

Actual selection of the profiles to be used in the study, their location and minimum number were determined by the need to delimit only regional associations of landform height and "peak" number. Line-of-sight profiles with a vertical scale of 1:4800 (400 feet per inch) were drawn from the lowest valley to the highest elevation shown on each map. A second profile was drawn across the primary profile to bisect the remainder of the map, and to serve as a check of the number of "peaks" shown on the first profile. Additional transects were drawn to supplement or test the above samples, namely: perpendicular on the map plane to the above lines; perpendicular to an apparent regional boundary; perpendicular to the topographic grain as shown on maps at the scale of 1:50,000 (crossing major linear features of the land, tributary valleys, floodplains, pediments, and the abrupt changes in slope which indicate sub-regional boundaries); and random transects.

2.3 Landform Classification.

By definition a region is a broad homogeneous geographic area. The initial criteria for landform homogeneity in terms of intervisibility (maximum hill heights and number of hills that would mask lines-of-sight) became the basis for the present classification system.

In regional studies it is more meaningful to include only those descriptors that will show broad comparative affinity rather than a large number of descriptors that will tend to give individual identity to small features and which will result in an unmanageable number of areas. In the present study only maximum hill height (local relief), modal hill height (modal local relief), and the number of positive features per mile were determined from the map profiles.

The maximum hill height in a profile, with the mode of hill heights measured in that profile, give an indication of the relative size of landforms in the region being sampled and the consequent length of lines-of-sight in the region. The number of positive features per

mile indicates the density of landforms or ruggedness of the topography rising above the plain or valley floor. The conversion of these data to positive features per kilometer is shown in Table 1. To adequately differentiate all elements of the landscape by numerical descriptors, class intervals were selected for the full range of measurements to be made in the study area with the parameters that had been selected. These numerical descriptors do not fully describe the individual land-forms in the study area, but they do provide a means for determination of the global incidence of these parameters and show areas suitable for detailed studies of representative types.

3. INSTRUCTIONS FOR CLASSIFYING LANDFORMS

3.1 Map selection.

The available coverage of tactical scale maps and aerial photographs for the study area determines the detail that will appear in the final product as well as the time that will be required in making a complete analysis of these materials. The scale of these materials, the contour-interval of hypsometry, date and methods of surveys, projection and method of compilation, and cartography vary widely for different parts of the world and will influence results obtained. Uniformity of results can be increased by use of the same series of maps for the entire study, such as Army Map Service Series M745 at a scale of 1:50,000 for the whole study area together with USAF air photo coverage at 1:25,000. If complete coverage of these materials is not available for the study area, other maps showing topography may be substituted only after checking their agreement in contour demarkation in areas of duplicated coverage.

The crudest topographic maps, those showing only spot elevations and hachures, may be used with aerial photographs to determine regions of maximum hill height only. They do not have sufficient slope detail for the other elements of the classification system.

Maps with elaborate detail, such as those at a scale of 1:5,000 give a precision to regional boundaries that cannot be transferred to smaller scale maps. The small bends and turns are lost within the width of a much more generalized boundary line through the area. Selection of map scale, therefore, should be related specifically to the use for which the work is intended. Maps of scales smaller than 1:100,000 (i.e., 1:250,000 etc.) are usually unsatisfactory for topographic analysis, but may be used to show national or continental distributions of regional features which had been determined from large scale maps.

Normally, if a choice is available, selection should be (1) largest scale that gives complete coverage of study area, (2) finest contour interval, or greatest number of contours per unit area, (3) photogrammetric, rather than compilation from reconnaissance methods, and (4) hypsometry, not plastic shading.

3.2 Map Analysis.

The established criteria and classification code (Table 1) dictate the order of activities during the analysis phase. Some supplemental suggestions may prove useful and time-saving.

Cover each map sheet with tracing paper, and work over a tracing table with a source of light under the map. After locating the highest and lowest elevation points on the map, and drawing a connecting line, the initial profile can be plotted directly over the line. (Note: the lowest elevation is usually on the edge of the map at the end of drainage lines; the highest point is usually on the opposite edge of the map sheet).

The difference in elevation between the highest and lowest elevations shown on the initial profile is the initial regional classifier. This figure is often misleading, especially if only one map sheet is completed for the entire region. It can be corrected by comparison, with data from adjoining sheets. A hill mass, for example, is often a part of a larger system, and may have to be re-classified. In other words, an entire hill mass with homogeneous characteristics should have one classifier for maximum hill height (local relief) regardless of the number of sheets on which it is depicted. If each large scale map area is plotted as a grid on a small scale national map, the overall distribution of each region can be seen (Figure 4).

After the regional pattern of maximum hill heights has been determined for the study area, an analysis of the profiles for each map sheet is conducted to find modal local relief and number of positive features. The number of profiles required for each sheet is dependent on the complexity of relief shown on the sheet. A sheet showing very little relief of any type could be adequately sampled with a single profile. Where there is equal and linear distribution of landforms across the sheet, one or two profiles may be sufficeint. The test for significance is seen in the amount of disagreement found in profiles in different parts of the map. Where two profiles agree in classification, there is probably no need for additional checking.

3.3 Profiling.

The initial profile is analyzed by counting the "peaks" shown on the line. For example, Figure 1 illustrates a profile with 3 such positive features. While this illustration is obviously in Region 6, because the "local relief" is in excess of 400 meters, two of the "peaks" are less than 35 meters in height and are initially classified in Region C for the modal hill height. This small number of positive features is not satisfactory without further checking. Obviously, several parallel profiles are required to substantiate this classification. However, if they are in agreement, the region would be classified as 6C, and further 6Ca because there are fewer than 0.8 positive features per kilometer.

Further study of the area illustrated in Figure 1 discloses that it is a rolling upland with deeply dissected valleys which have eroded some of the borders leaving a rough "badlands" type of topography in several places. This typical situation requires several additional profiles at right angles to the initial profile in order to provide an adequate sample of heights and number of hills per kilometer in the region.

A clear plastic template with elevation and distance ticks for the scale being used will give a rapid result. The spacing of coordinate points along the profile is dependent on the purpose of classification; checking elevations at each 200 meters of horizontal distance may be satisfactory for a reconnaissance type of evaluation, but it will not yield sufficient information for determination of accurate heights and numbers of positive features per kilometer. The latter requires a coordinate spacing at least 50 meters.

The profile can show only what is indicated in the hypsometry of the map. A contour interval of 10 meters will screen all features of a lesser height between these intervals. A classification system based on "peaks" being identified as at least 3 meter (10 foot) changes in elevation requires photographic stereocomparography to provide the essential data. Otherwise, the basis should be changed.

The profile clearly shows regional homogeneity. Any question can usually be resolved with additional profiling. Where a single large peak dominates a low hill mass, it is obviously in a different region, and should be delimited accordingly. Where a lowland area is interrupted by a mass of slightly rolling landforms, these "peaks" should be classified as hills clearly distinct from the lowland. The profiling must sample all portions of the map sheet that appear to be different in any way from the initial profile.

When profiling is complete for the map sheet under study, it will be found that profile segments may have been classified to fall into different regions and, consequently, the maximum hill height (local relief) of the initial profile is no longer applicable. Each profile segment will require a new determination of maximum hill height (local relief).

In some situations the maximum hill height (local relief) will have to be extended beyond the initial profile to include parts of adjoining maps. This usually occurs in areas where the adjacent area is only slightly lower than the initial profile indicator. Where a very small region of a different classification has been delimited, it may be included as a part of the higher region if it could not be seen on a small scale map (see Figure 2). In the latter situation, the modal hill height and number of positive features per mile should be recomputed to include all of the data for the new combined region.

"Peaks" along the profile are counted for positive features only when their shortest slope is in excess of 3 meters (10 feet). However, in the determination of modal hill height, all slopes are counted along the profile (both upslopes and downslopes of all discernible "peaks"). Slopes of different angles between a given peak and an adjacent valley are counted as a single slope.

3.4 Regionalization.

In the present classification, the maximum hill height (local relief) has been designated as the regional determinant, and the modifiers (modal hill height and positive features per mile) are indicators of subregions because they divide the maximum hill height region into smaller areas (see Figures 4 and 5). Either of these modifiers may be used as the scale criteria for a particular purpose as in Figure 5.

Figure 1 illustrates several abrupt changes in slope (i.e. points A and B) or nickpoints. Regional boundaries are established by connecting nickpoints which have been identified on the profiles and plotted as x points on the small scale national map. The contour line at a particular nickpoint is followed across the map to connect with an adjacent nickpoint of the same or related slope to interpolate regional boundaries. For example, if a given region as delimited by nickpoints is shown on two adjacent profiles to be at least the 400 meter elevation, the contour lines demarking that elevation would be used in determining the regional boundary on a given map sheet between these profile points. This boundary, together with its segments taken from adjoining 1:50,000 scale sheets, would then be transferred to a smaller scale map (i.e., 1:250,000) to show the extent of the whole region or subregion (see Figures 6, 7, and 8).

In some instances, it is necessary to move the line connecting nickpoints upslope or downslope from the indicated contour in order to more accurately determine the regional boundary, but the configuration of the line should conform to the nearest higher contour shape.

Boundary lines are zones of transition from one type of landform complex to another, and the indicated boundary may have been "smoothed" or generalized to fit a different scale map. For this reason, an ideal typical regional sample should be obtained in core areas rather than near boundary lines.

4. SUMMARY AND CONCLUSIONS

To determine criteria for regional landform boundaries and to draw maps to include this information, it is necessary (1) to select pertinent landforms,(2) to determine landform characteristics that have regional meaning, (3) to devise a means for classifying these characteristics and accurately locating them, (4) to develop a system of symbolization

to assist in the presentation of the areal differentiation of these landforms, and (5) to relate these to specific problems requiring landform input.

The present scheme was devised to show the application of landform characteristics to intervisibility on a regional basis. In attempting to describe landform features on this basis it is necessary to determine how detailed the description must be in order to shown the relationship of this feature to others of a similar type and to present the unique characteristics that distinguish this feature from all others. In regionalization the primary requirement is to show broadened relationships, and therefore only a few descriptors are required to show individual differences. Selection of the proper descriptor categories tends to eliminate questionable or unlike features and results in homogeneous features.

In the present study the features selected were maximum hill height, modal hill height and number of positive features per mile. The combination of coded values for each of these features became the regional classification. Research is being conducted on additional criteria for possible inclusion in the classification system. The test is whether these would add significantly to the understanding of the range of natural conditions in each region without greatly increasing the number of subregions. Also, a determination should be made of the need for such additional information, and whether it could be analyzed more efficiently on a separate map.

In the present study data, each of the above descriptors was taken from individual line-of-sight profiles from 1:50,000 scale maps for the study area. The interpretation of profile data was assisted by compiling frequency curves for each of the above descriptors. The profiles are useful for a number of investigations in addition to intervisibility, such as those involving defilade, enfilade, slope and gradient.

A few regions contain a large fraction of the total area. Table II shows that six of the most frequently occurring landform regions comprise over 44 per cent of the total area of the Federal Republic of Germany. Terrain models compiled from data representative of these regions would yield a large areal significance from a relatively few types.

Several smaller regions were combined in order to develop the larger regions. In some cases this resulted in double peaked histograms for modal hill height. If necessary, these regions may be reclassified on larger scale maps for purposes of war gaming. When taking a terrain sample from such regions, care should be exercised in the interpretation of the resulting slope data.

The Landform Classification System has been successfully applied to several world environments (Thailand, Vietnam, Germany, and the United States). The system is especially useful in depicting analogous terrain from various parts of the world. It gives a clear picture of landform differences applicable to intervisibility, mobility, fire problems, target acquisition, and other military uses. The data obtained facilitate the development of line-of-sight models and representative terrain models. The system is a positive step forward in the development of terrain quantification concepts.

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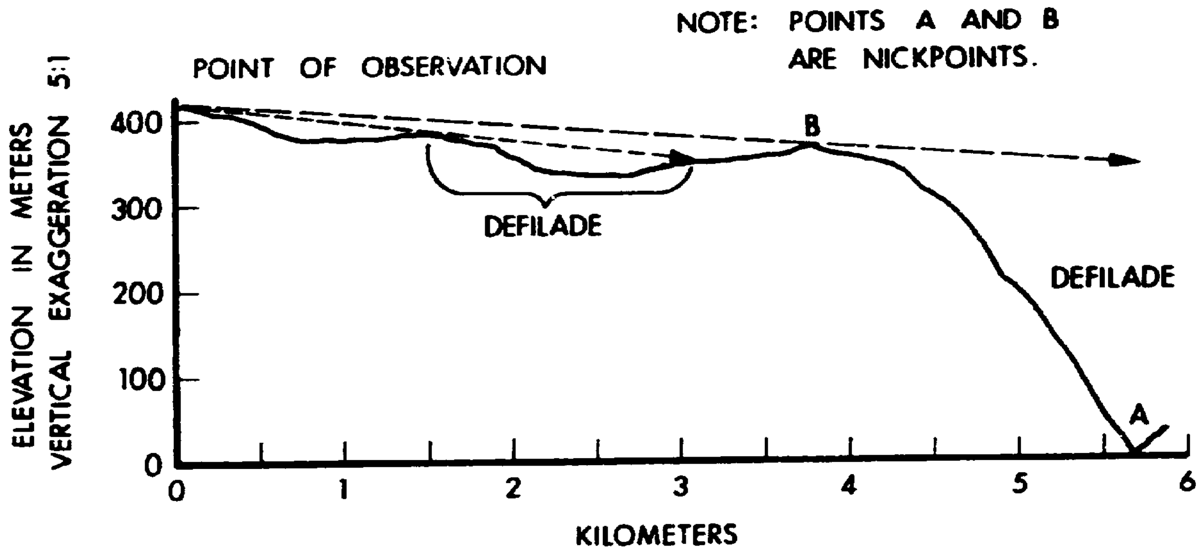

Figure 1. Line-of-Sight Profile, Region 6Ca.

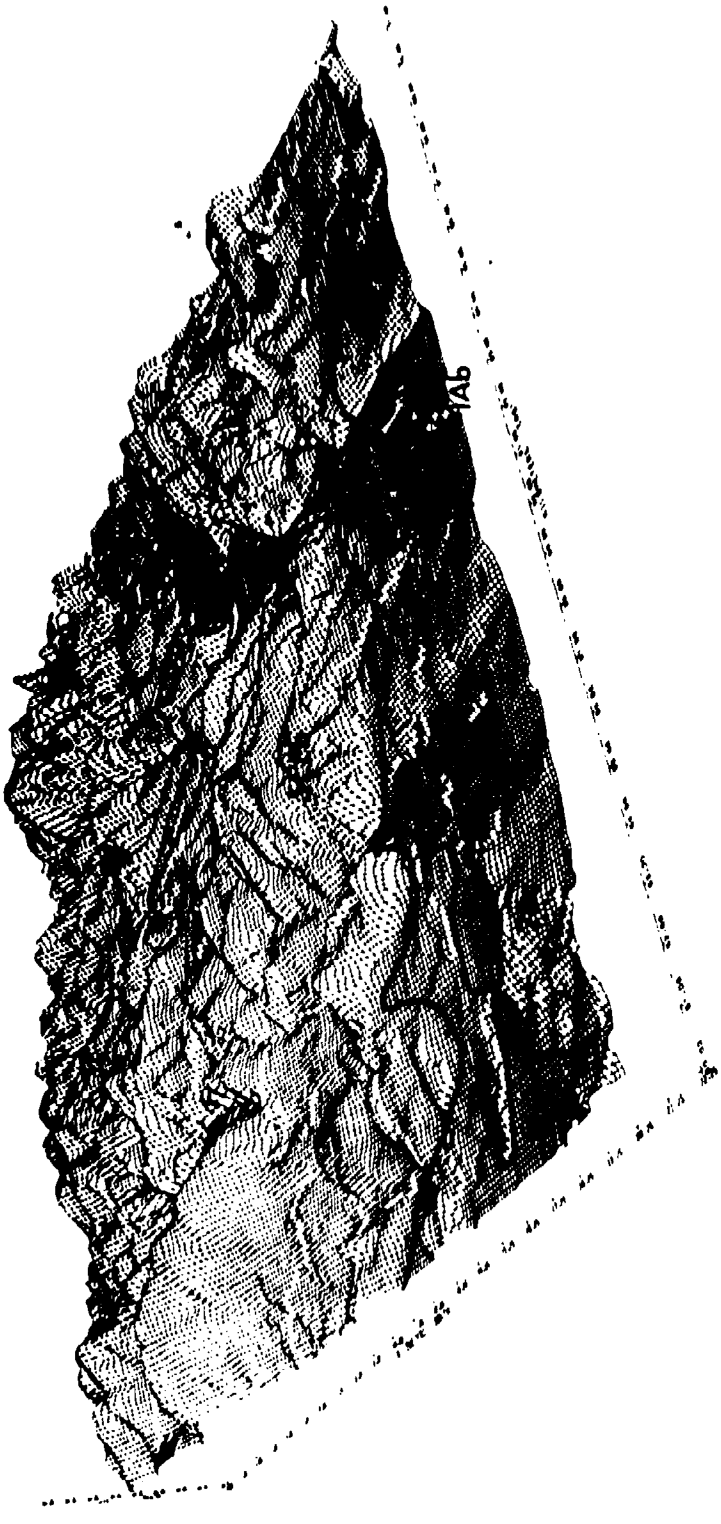

Figure 2. Fritzlar Area, Federal Republic of Germany.

FREQUENCY DISTRIBUTION GRAPHS SHOWING MAXIMUM HILL HEIGHT (Local Relief)
FEDERAL REPUBLIC OF GERMANY

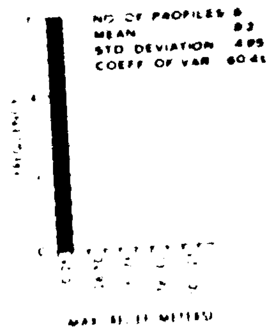

FIGURE 3a.
REGION 1

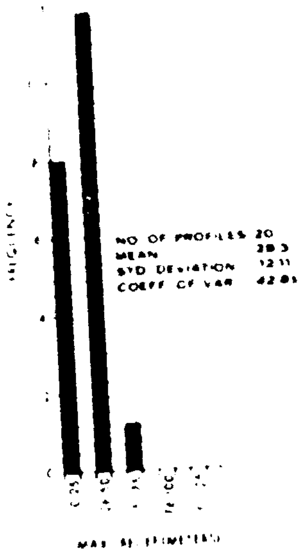

FIGURE 3b.
REGION 2

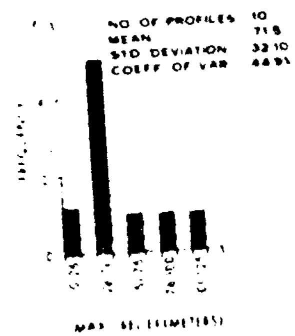

FIGURE 3c
REGION 3

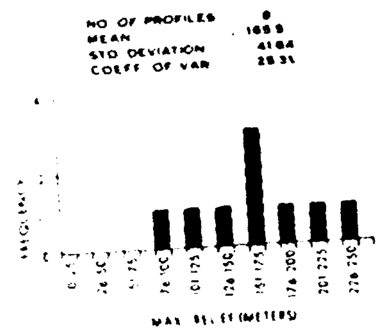

FIGURE 3d.
REGION 4

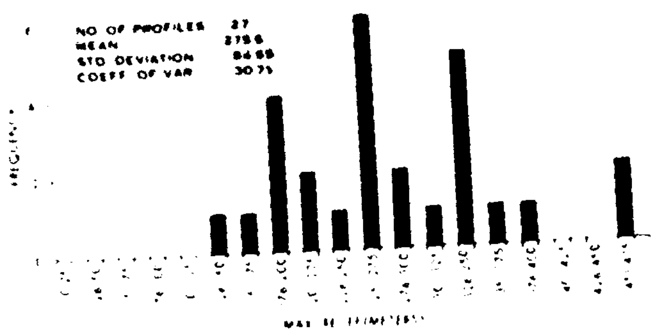

FIGURE 3e.
REGION 5

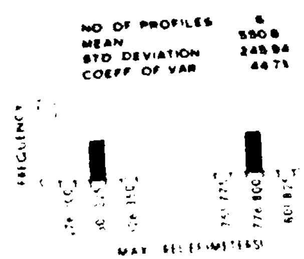

FIGURE 3f.
REGION 6

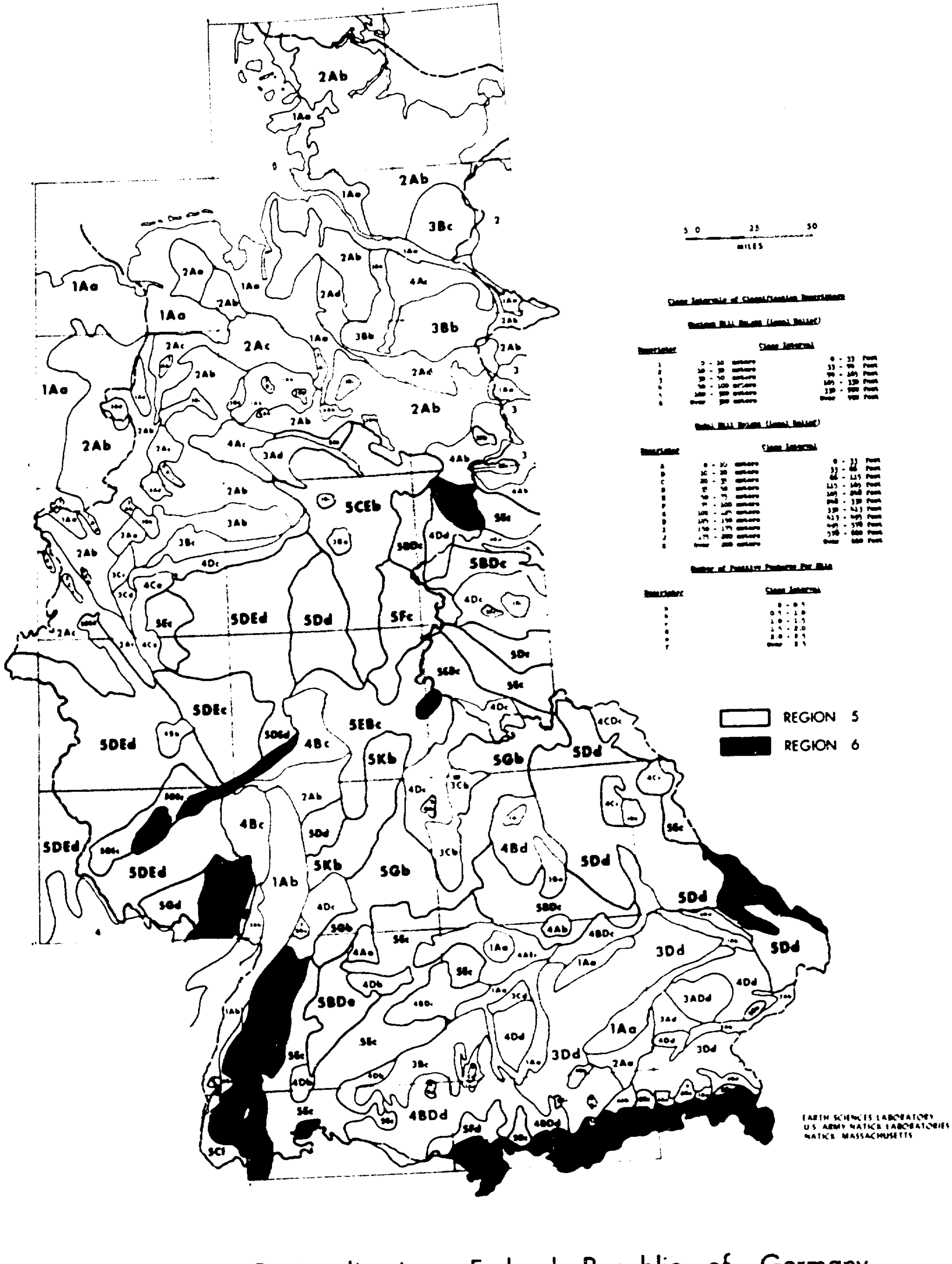

Figure 4. Terrain Regionalization, Federal Republic of Germany.

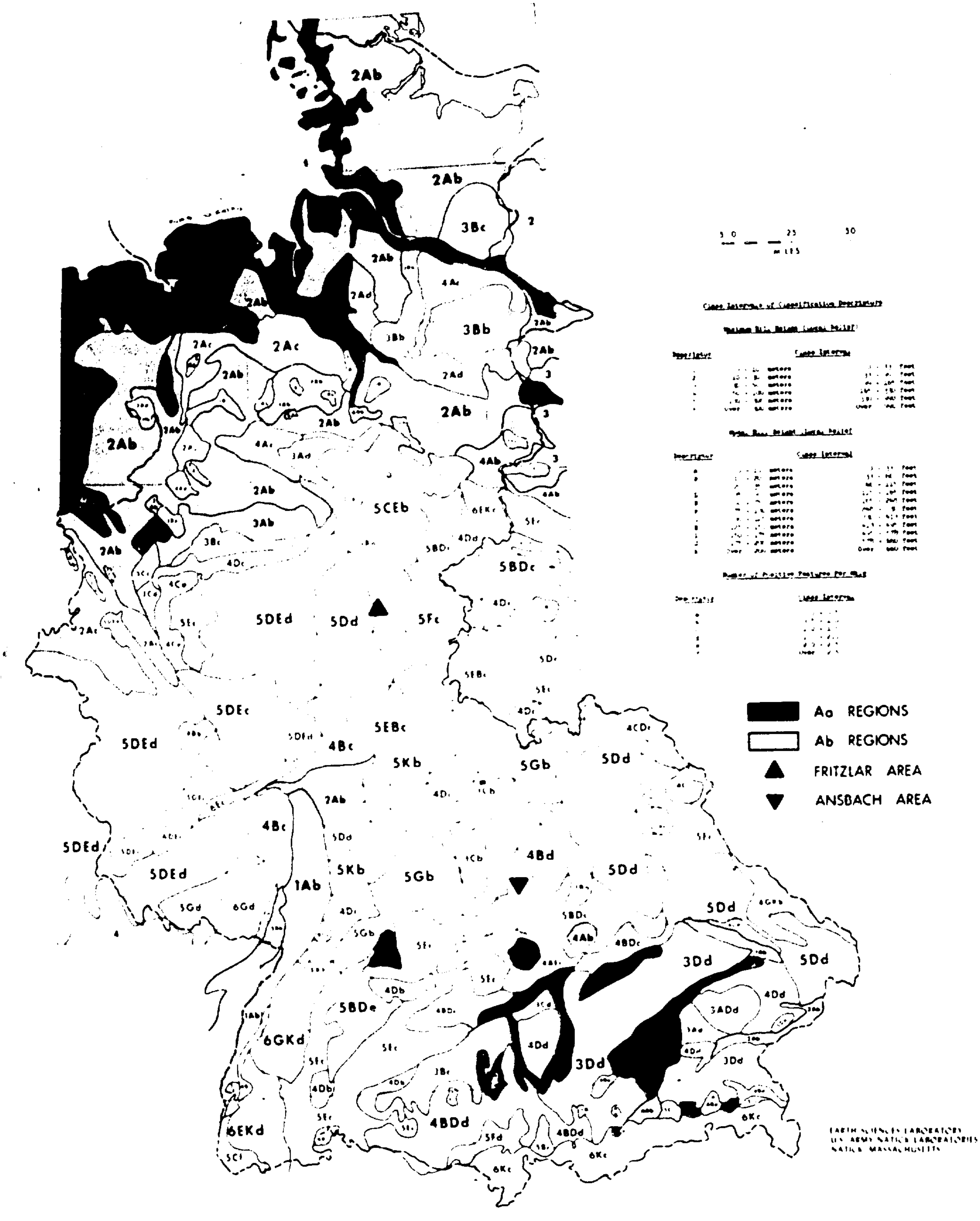

Figure 5. Terrain Regionalization, Federal Republic of Germany.

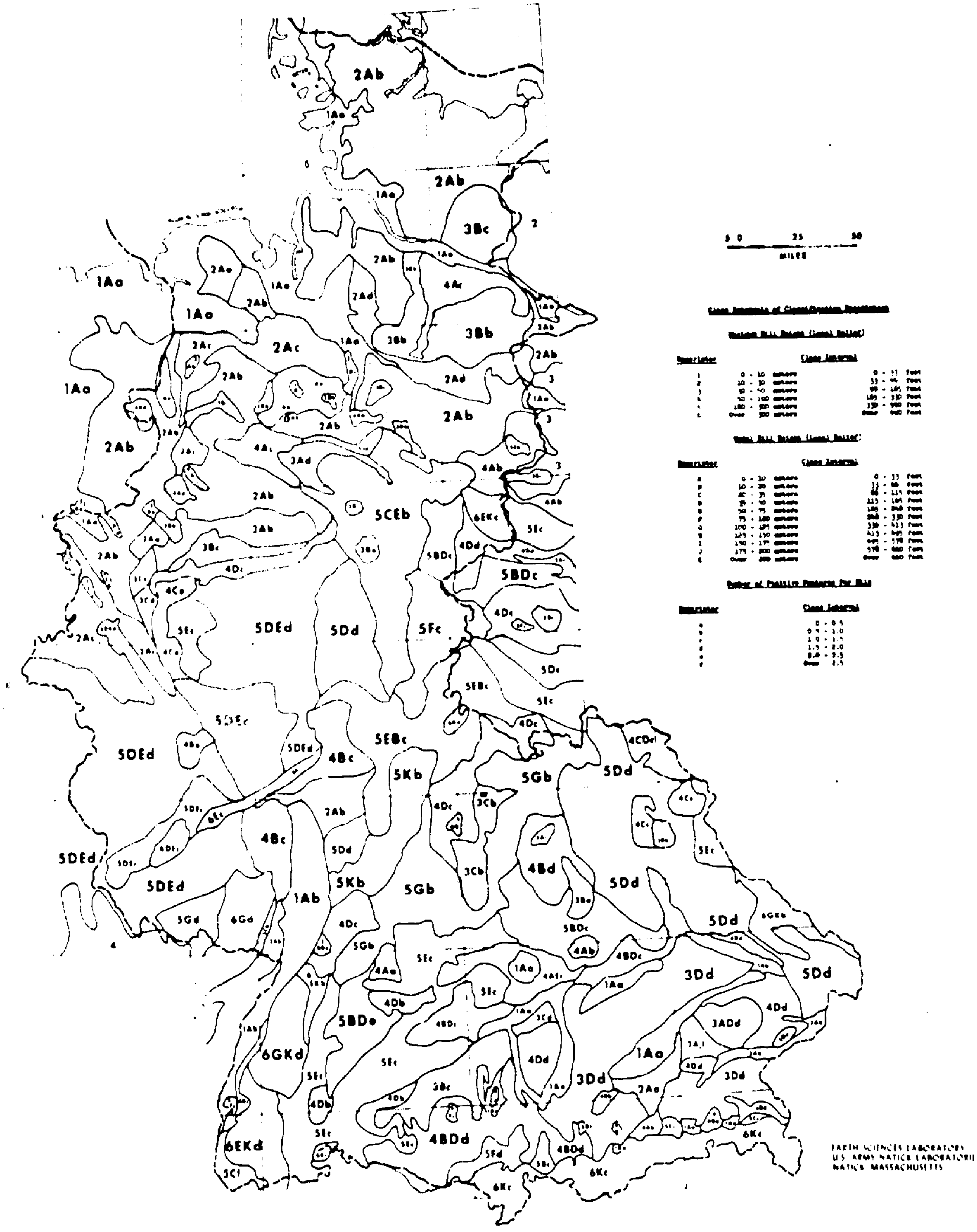

Figure 6. Terrain Regionalization, Federal Republic of Germany.

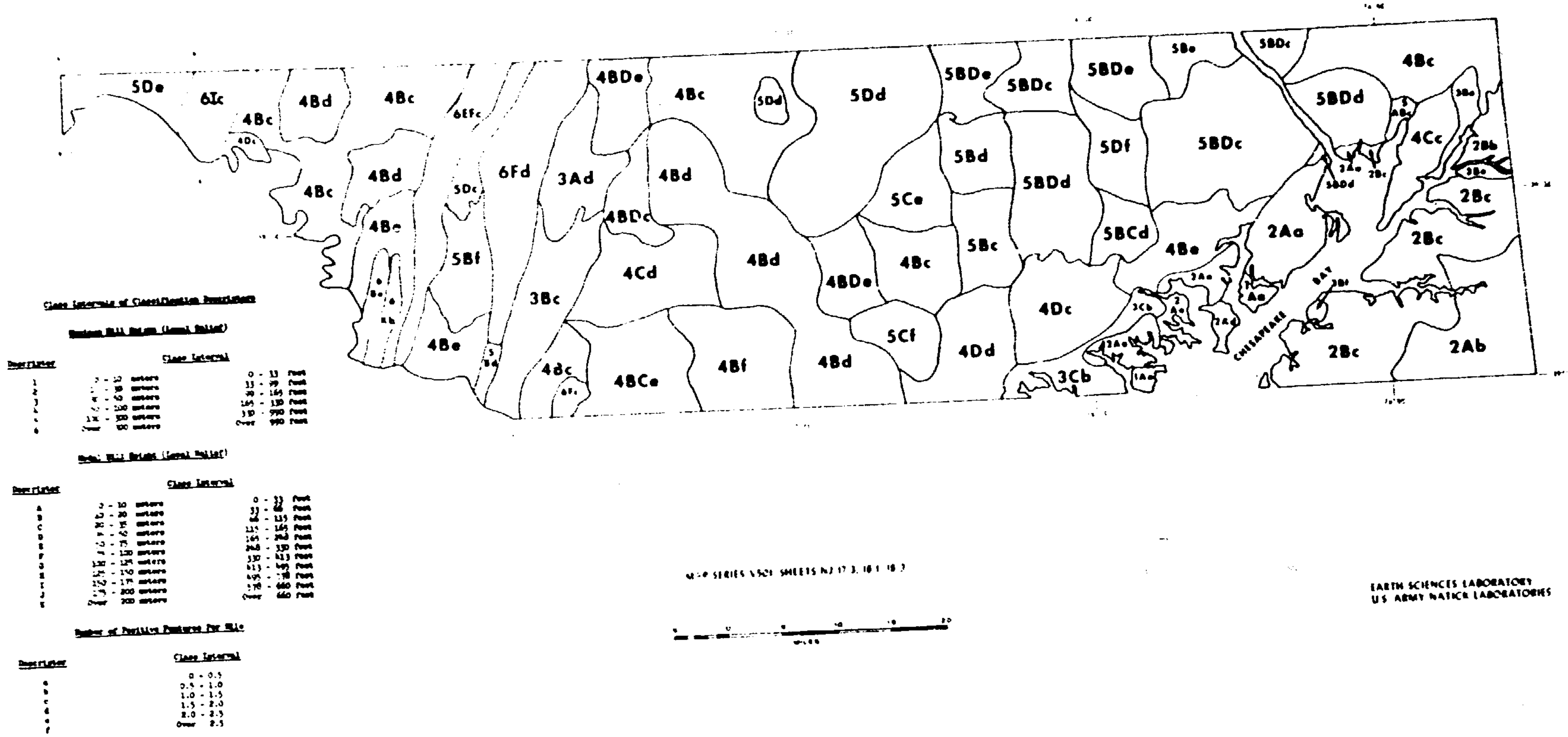

Figure 7. Terrain Regionalization of Northern Maryland.

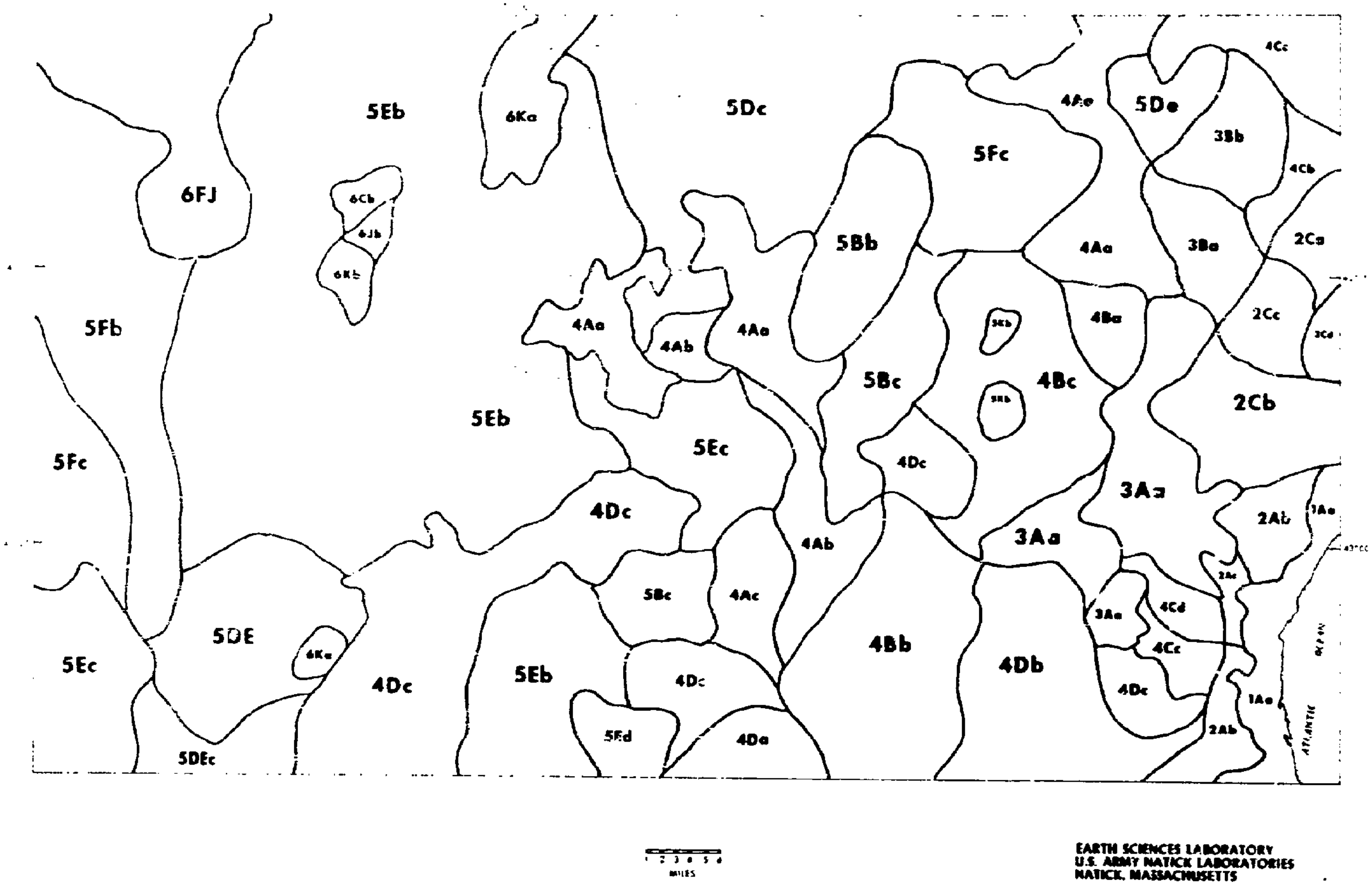

Figure 8. Terrain Regionalization of Southern New Hampshire.

Table I. Class Intervals of Classification Descriptors.

MAXIMUM HILL HEIGHT (LOCAL RELIEF)

DESCRIPTOR	CLASS INTERVAL	
1	0 - 10 METERS	0 - 33 FEET
2	10 - 30	33 - 99
3	30 - 50	99 - 165
4	50 - 100	165 - 330
5	100 - 300	330 - 990
6	OVER 300	OVER 990

MODAL HILL HEIGHT (LOCAL RELIEF)

DESCRIPTOR	CLASS INTERVAL	
A	0 - 10 METERS	0 - 33 FEET
B	10 - 20	33 - 66
C	20 - 35	66 - 115
D	35 - 50	115 - 165
E	50 - 75	165 - 248
F	75 - 100	248 - 330
G	100 - 125	330 - 413
H	125 - 150	413 - 495
I	150 - 175	495 - 578
J	175 - 200	578 - 660
K	OVER 200	OVER 660

NUMBER OF POSITIVE FEATURES PER MILE

DESCRIPTOR	CLASS INTERVAL	
a	0 - 0.8 / KILOMETER	0 - 0.5 / MILE
b	0.8 - 1.6	0.5 - 1.0
c	1.6 - 2.4	1.0 - 1.5
d	2.4 - 3.2	1.5 - 2.0
e	3.2 - 4.0	2.0 - 2.5
f	OVER 4.0	OVER 2.5

Table II. Landform Breakdown. (W. Germany)

TERRAIN TYPE	OCCURRENCE FREQUENCY	AREA (km^2)	PERCENT AREA
1Aa	14	16,688	7
2Ab	11	33,164	13
3Bc	7	6,239	3
4Dc	10	9,298	4
5Dd	5	38,865	16
6Kc	2	4,946	2
	49	109,200	45

FRACTION OF TOTAL COMPARTMENTS: 49/154 = 32%

FRACTION OF TOTAL AREA: 109, 200/ 248, 014 = 44%

APPENDIX A

AMSAA Sampling of Representative Terrain

AMSAA selected sample areas to be digitized from the maps prepared under the Natick Landform Classification System. In the original plan these samples were to be taken from each of the type regions developed in this study (i.e., a sample would be taken from region 5BDc, etc.). A basic assumption was that a sample of a given size would be as valid as the same size sample taken from any other part of the same region. Where complete coverage was not feasible, due to the amount of material to be handled, the samples would be selected from that part of the region exhibiting the fewest unique features.

The sampling technique consisted of (1) determining subregions of required homogeneous landform characteristics, (2) selecting representative sample areas for each of these regions, and (3) mapping the hypsometry of each of the sample areas.

The size of the sample was to be 12 km X 12 km. Each area was covered by a series of 1 km X 1 km maps at the scale of 1:1250, having a sheet size of 30" X 30" (see Figures 9 and 10); the contour interval was 1 meter. Drawing the contour lines on these maps involved stereocomparagraphy of low-level aerial photography, preferably taken at 5000 feet or lower. This photography is seldom available, and the resulting amount of detail to be shown within a subregion is dependent on existing photo coverage, or it may be derived from large scale maps. Most of the available photography is from the altitude of 30,000 feet or higher.

Figure 9 shows the hypsometry for 1 sq. km in the Ansbach area of Germany which was classified as 5BDc under the present system (see Figure 4-5). Figure 10 shows the hypsometry for 1 sq. km in the Aberdeen area of Maryland which also is classified as 5BDc (see Figure 7). A comparison of these two maps indicates general agreement in number of contours per unit of traverse across any part of either map. The slope angles on both maps are similar, and the general physiognomy of the terrain is considered to be analogous. Other than the neat line, these maps show only contour lines which are read by digitizing machines and recorded on magnetic tape as known elevations at known geographical coordinates. These data can be readily retrieved to construct terrain models or line-of-sight models for use in systems analysis of materiel.

Hypsometric maps show only the contours, they do not identify landforms. They are not intended for mobility evaluation or for siting equipment or installations. No attempt was made to indicate abrupt changes in relief (boulder fields, stumps or downed trees) between contour lines on these maps even though these features are shown on the aerial photographs.

Hypsometric maps at the scale of 1:1250 constitute representative samples of subregions if they are taken from "cores" rather than from regional borders. The incidence of unique conditions or atypical features in the data usually indicates that a regional boundary has been crossed whether it has been accurately demarked or not, and these data should not be used in problems where representative topography of a particular subregion is needed.

Complete agreement in details between representative samples, such as that shown in Figures 9 and 10, may not occur in other parts of the subregion. Problems encountered with general landform conditions in one part of the subregion may be expected to occur commonly throughout the same subregion. Identical classification of landforms from two separated areas is merely an indication of repetition of the same landscape features selected for use in the classification system; it does not imply that all minor features in the two areas will conform. Additional classification digits are required to describe the character of these additional aspects of the subregion. The regional classification for topography in an extremely small area, such as one square decameter, may exactly match that for another small area, i.e., have the same physical features in it. It is possible to classify areas of this scale for specific military needs using the technique developed in the present study.

The major advantage of the type of displays developed in the present study is that relatively few areas require detailed mapping or conversion to numbers by digitization machines to cover most of the terrain types in a given country. One sample of topographic conditions from each of the subregions determined in this study would give a good representation of the total range of land forms to be found in large diversified territories such as the Federal Republic of Germany (Figure 6) or the Northeastern United States (Figures 7 and 8). Use of the data from analogs of the same subregions in other countries, such as for South Vietnam in Western Thailand or Panama, would permit testing of equipment under identical landform conditions without actually visiting politically inaccessible areas.

Digitization of sample hypsometric data from such analogous areas will permit the utilization of representative topography from any world area for war gaming, equipment performance evaluation, machine studies of materiel effectiveness, and other systems analyses. The hypsometric data in the present study are particularly applicable to studies of intervisability and the masking effect of terrain. They can also be used for rate of march, mobility, munition effects in defilade - enfilade situations, field of fire, logistics, and related military problems involving the comparison of operations requirements with a possible environmental limitation due to the masking effect of landforms or the battlefield configuration.

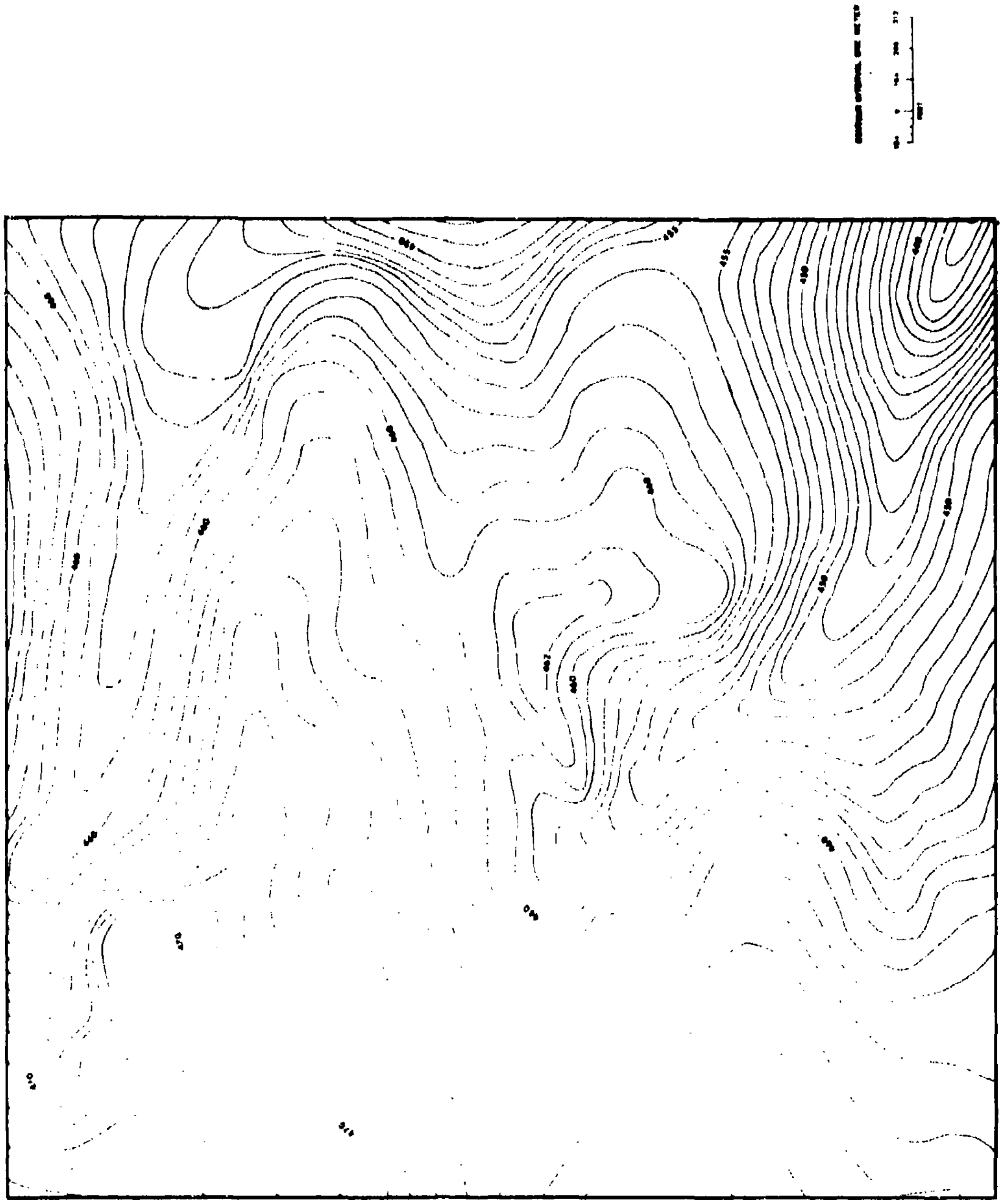

Figure 9. Ansbach Area, Germany

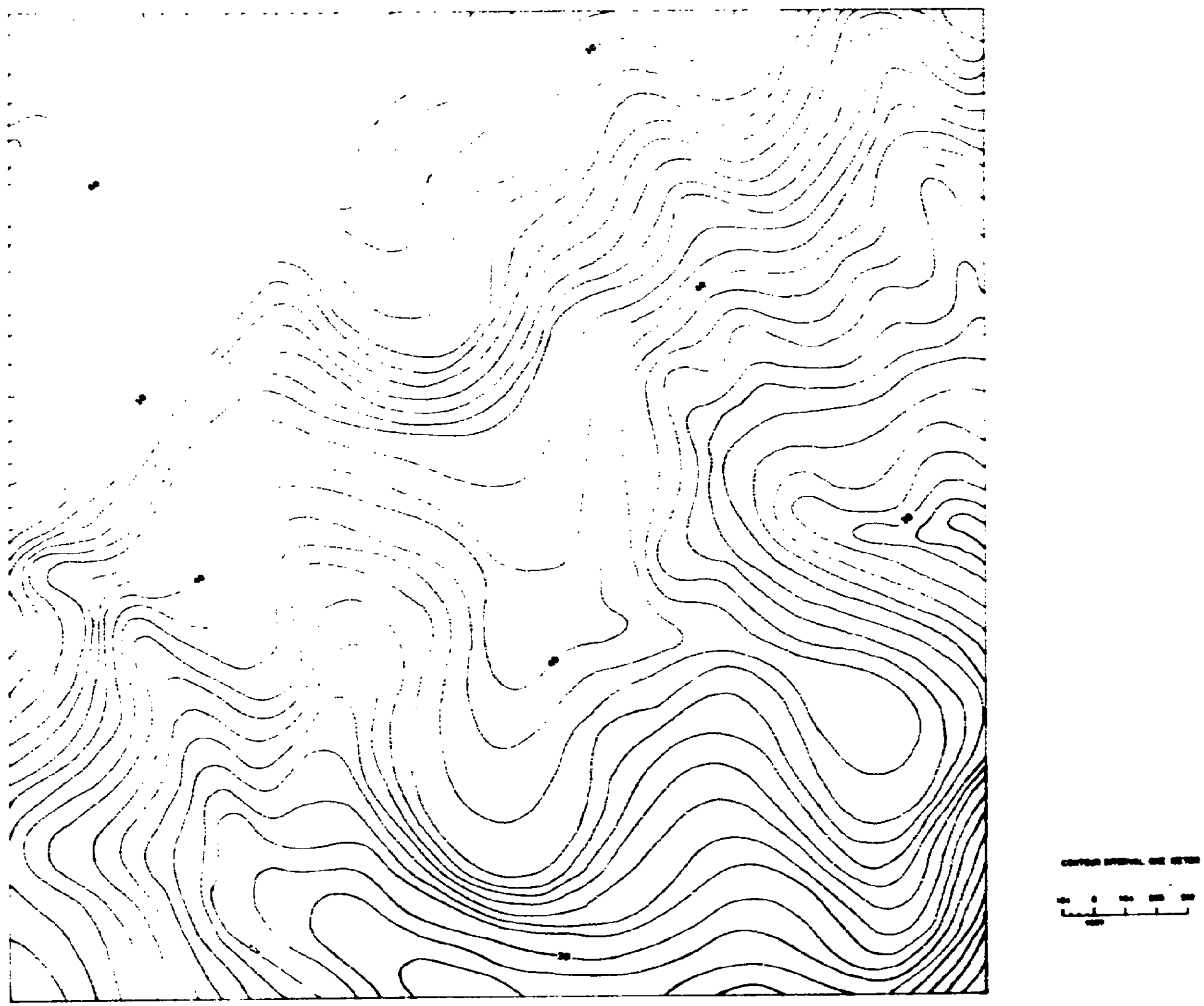

Figure 10. Aberdeen Area, Maryland

APPENDIX B

Planimetry of Landform Classification Regions Within West Germany

Warren K. Olson

The distribution of landform compartments as defined for West Germany under the Natick classification system has been investigated at USAMSAA, using an electronic planimeter to determine the frequency of occurrence and percent areal coverage for each landform type depicted in Figure 6. The Natick system divides West Germany into 154 landform compartments, 69 of which are unique combinations of identifiers pertaining to maximum local relief, modal local relief and number of positive features per mile.

Table III indicates the areal distribution of landforms by maximum local relief only. It can be seen from the table that if Regions 1 and 2 are taken to constitute "flat" terrain, approximately 28 percent of West Germany would fall into this category. Similarly, defining Regions 3, 4 and 5 to represent moderately rolling to rolling terrain, results in 66 percent of the West German terrain being so classified. The remaining 6 percent would be categorized as very rolling to rugged terrain.

This coarse breakdown of terrain into categories for comparison with other systems may be further refined by including the descriptions of amplitude (modal local relief) and frequency (positive features per mile) in the generalization. These letter descriptors indicate the type and magnitude of the oscillatory nature of the macro-terrain. As indicated in Figure 5, types Aa and Ab are generally flat regardless of the identity of the maximum local relief descriptor. Nearly all compartments exhibiting Aa or Ab type relief are of classes 1 or 2. This trend is evident throughout Table IV, i.e., those regions exhibiting large maximum local reliefs are quite likely to have correspondingly large modal local reliefs. As a consequence of the construction of the classification system, the modal local relief of a compartment must be no greater than the maximum local relief. There also appears to be a correlation between the maximum local relief and the frequency with which positive features occur (i.e., the frequency of the sine wave which, together with its expected amplitude, serve to characterize the expected oscillation within a given compartment).

The data presented in Table IV were used to construct Table II, in which the six most frequently occurring terrain types in West Germany are listed. In some instances, compartments within one interval of the most commonly occurring class of modal local relief or positive features per mile were included in the computation of the area associated with

each of the six terrain types. This data will be used in the future to isolate those types of terrain to be given the greatest emphasis in a study designed to validate statistically the use of the Natick Landform Classification System in solving problems in military operations research.

TABLE III. PLANIMETRY SUMMARY BY REGION (MAXIMUM LOCAL RELIEF)

REGION	PERCENT AREA	NUMBER OF COMPARTMENTS	UNIQUE DESCRIPTORS
1	9.2	17	2
2	18.5	19	6
3	12.6	34	14
4	14.7	41	18
5	38.7	32	19
6	6.3	11	10
TOTALS:	100.0%	154	69

TABLE IV. PLANIMETRY OF LANDFORM CLASSIFICATION REGIONS WITHIN WEST GERMANY

	DESCRIPTOR	NUMBER	AREA (KM^2)	TOTAL AREA
REGION 1:				
	Aa	1	11065	
		2	325	
		3	1674	
		4	373	
		5	205	
		6	106	
		7	293	
		8	59	
		9	1371	
		10	648	
		11	78	
		12	119	
		13	25	
		14	347	
				16,688
	Ab	1	1547	
		2	4044	
		3	652	
				6,243
				22,931

Percent Coverage of West Germany - 9.246%
Number of Compartments - 17
Number of Unique Descriptors - 2

TABLE IV. PLANIMETRY OF LANDFORM CLASSIFICATION REGIONS WITHIN WEST GERMANY (CONT)

REGION 2:

DESCRIPTOR	NUMBER	AREA (KM^2)	TOTAL AREA
Aa	1	1013	
	2	971	
			1,984
Ab	1	10790	
	2	3058	
	3	724	
	4	83	
	5	9638	
	6	5966	
	7	18	
	8	1568	
	9	671	
	10	607	
	11	41	
			33,164
Ac	1	3311	
	2	516	
	3	3844	
	4	372	
			8,043
Ad	1	2598	
			2,598
Bb	1	45	
			45
			45,834

Percent of Grand Total Area = 18.480%
Number of Compartments = 19
Number of Unique Descriptors = 6

TABLE IV. PLANIMETRY OF LANDFORM CLASSIFICATION REGIONS WITHIN WEST GERMANY (CONT)

REGION 3:

DESCRIPTOR	NUMBER	AREA (KM^2)	TOTAL AREA
Ab	1	78	
	2	2149	
	3	422	
			2,649
Ac	1	183	
	2	136	
			319
Ad	1	263	
	2	1013	
	3	650	
			1,926
AD d	1	1198	
			1,198
Ba	1	235	
	2	573	
			808
Bb	1	4180	
	2	127	
	3	254	
	4	233	
			4,794
Bc	1	1988	
	2	357	
	3	186	
	4	106	
	5	1081	
	6	2479	
	7	42	
			6,239
BD e	1	122	
			122

TABLE IV. PLANIMETRY OF LANDFORM CLASSIFICATION REGIONS WITHIN WEST GERMANY (CONT)

	DESCRIPTOR	NUMBER	AREA (KM^2)	TOTAL AREA
REGION 3 (CONT):				
	Cb	1	1560	
		2	36	
				1,596
	Cc	1	369	
		2	74	
				443
	Cd	1	321	
		2	333	
				654
	Db	1	213	
				213
	Dd	1	7519	
		2	2439	
				9,958
	Undefined	1	16	
		2	78	
				94
				31,013

Percent of Grand Total Area = 12.505%
Number of Compartments = 34
Number of Unique Descriptors = 14

TABLE IV. PLANIMETRY OF LANDFORM CLASSIFICATION REGIONS WITHIN WEST GERMANY (CONT)

REGION 4:

DESCRIPTOR	NUMBER	AREA (KM^2)	TOTAL AREA
Aa	1	397	
			397
Ab	1	164	
	2	1539	
	3	256	
	4	271	
	5	31	
			2,261
Ac	1	1886	
	2	1265	
	3	126	
			3,277
Ad	1	264	
			264
AB e	1	182	
			182
AE c	1	1809	
			1,809
Bb	1	435	
	2	180	
			615
Bc	1	1825	
	2	1767	
	3	396	
	4	39	
			4,027
Bd	1	1853	
	2	291	
			2,144

TABLE IV. PLANIMETRY OF LANDFORM CLASSIFICATION REGIONS WITHIN WEST GERMANY (CONT)

	DESCRIPTOR	NUMBER	AREA (KM^2)	TOTAL AREA
REGION 4 (CONT):				
	BD c	1	1490	
		2	1502	
				2,992
	BD d	1	4681	
				4,681
	Cc	1	450	
		2	435	
				885
	Cd	1	52	
				52
	Ce	1	1106	
				1,106
	CD c	1	1064	
				1,064
	Db	1	575	
		2	560	
		3	343	
				1,478
	Dc	1	1385	
		2	2320	
		3	1351	
		4	141	
		5	31	
				5,228

TABLE IV. PLANIMETRY OF LANDFORM CLASSIFICATION REGIONS WITHIN WEST GERMANY (CONT)

	DESCRIPTOR	NUMBER	AREA (KM^2)	TOTAL AREA
REGION 4 (CONT):				
	BD c	1	1490	
		2	1502	
				2,992
	BD d	1	4681	
				4,681
	Cc	1	450	
		2	435	
				885
	Cd	1	52	
				52
	Ce	1	1106	
				1,106
	CD c	1	1064	
				1,064
	Db	1	575	
		2	560	
		3	343	
				1,478
	Dc	1	1385	
		2	2320	
		3	1351	
		4	141	
		5	31	
				5,228

TABLE IV. PLANIMETRY OF LANDFORM CLASSIFICATION REGIONS WITHIN WEST GERMANY (CONT)

	DESCRIPTOR	NUMBER	AREA (KM^2)	TOTAL AREA
REGION 4 (CONT):				
	Dd	1	676	
		2	274	
		3	1605	
		4	312	
		5	1203	
				4,070
				36,632

Percent of Grand Total Area = 14.730%
Number of Compartments = 41
Number of Unique Descriptors = 18

TABLE IV. PLANIMETRY OF LANDFORM CLASSIFICATION REGIONS WITHIN WEST GERMANY (CONT)

	DESCRIPTOR	NUMBER	AREA (KM^2)	TOTAL AREA
REGION 5:	Bc	1	281	
		2	20	
				301
	BD c	1	3823	
		2	1350	
				5,178
	BD d	1	2144	
				2,144
	Cb	1	152	
				152
	Cc	1	93	
		2	174	
				267
	Cf	1	545	
				545
	CE b	1	13192	
				13,192
	Dd	1	3485	
		2	874	
		3	12472	
				16,831
	De	1	126	
				126
	DE c	1	934	
		2	775	
		3	3967	
				5,676

TABLE IV. PLANIMETRY OF LANDFORM CLASSIFICATION REGIONS WITHIN WEST GERMANY (CONT)

	DESCRIPTOR	NUMBER	AREA (KM^2)	TOTAL AREA
REGION 5 (CONT):				
	DE d	1	8286	
		2	13748	
				22,034
	Eb	1	142	
				142
	Ec	1	1185	
		2	850	
		3	10378	
				12,413
	Fc	1	2760	
		2	67	
		3	74	
				2,901
	Fd	1	911	
				911
	Gb	1	93	
		2	8320	
				8,413
	Gd	1	1218	
				1,218
	Ja	1	348	
				348
	Kb	1	3190	
				3,190
				95,982

Percent of Grand Total Area = 38.700%
Number of Compartments = 32
Number of Unique Descriptors = 19

TABLE IV. PLANIMETRY OF LANDFORM CLASSIFICATION REGIONS WITHIN WEST GERMANY (CONT)

	DESCRIPTOR	NUMBER	AREA (KM^2)	TOTAL AREA
REGION 6:				
	DE c	1	525	
				525
	EC	1	778	
				778
	EK b	1	482	
				482
	EK c	1	869	
				869
	EK d	1	2255	
				2,255
	Gd	1	1809	
				1,809
	GK b	1	1632	
				1,632
	GK d	1	2243	
				2,243
	Ka	1	183	
				183
	Kc	1	4886	
		2	60	
				4,946
				15,722

Percent of Grand Total Area = 6.339%
Number of Compartments = 11
Number of Unique Descriptors = 10

Grand Total Area = 248,014